Indian J. Phys. 43 184—195 (1969)

Sunrise effect in the intensity of atmospherics at low frequencies

By A. K. Sen and M. K. Das Gupta

Institute of Radio Physics and Electronics, University of Calcutta

(*Received January 22, 1969 Resubmitted May 15, 1969*)

Round the clock observations of the integrated field intensity of atmospherics (IFIA) at the low frequencies, 30, 120 and 210 Kc/s, recorded in Calcutta, exhibit a remarkable sunrise effect. The results of a detailed study of the effect are presented. The duration of the effect, the frequency dependence of the duration as also the times of start and end of the effect are critically examined in relation to the location of the source and the existing knowledge of radio wave propagation at low frequencies.

Introuction

Important changes occur in the ionospheric structure during the periods of sunrise and sunset. The field intensity of distant atmospherics received at a place through ionospheric propagation, therefore, exhibit changes both during sunrise and sunset. Extensive studies have been made in different countries on the so called sunrise and sunset effects in the level of atmospherics observed at various frequencies and the results obtained have been reported in the literature (Thomas & Burgess 1947). Namba (1933) gave an explanation of the sunrise and sunset effects observed on very long waves in terms of a "metallic" and "dielectric" type of ionospheric reflection occurring in the day and night-sides of the ionosphere, respectively. Observations by Potter (1931) in the high frequencies and by Khastgir & Ali (1942) at medium frequencies indicated that a sharp single or sometimes a double peak in the radio noise level occurs just before and just after sunset and sunrise, respectively. They have given similar explanations of the peaks of noise level, During sunset, with the gradual disappearance of the solar ionizing radiations, the electron density of the *D*-layer as well as that of the *E*-layer decreases. As a result non-deviative absorption in the *E*-layer increases, while at the same time deviative obsorption in the *E*-layer increases. At the beginning, the increasing *E*-layer absorption is predominant thereby decreasing the intensity, while after sunset the decreasing *D*-layer absorption becomes more effective causing an increase of intensity. The single peaks near sunrise have also been explained by a similar reasoning. The double peaks sometimes observed can be explained in terms of a sudden "jumping" of the reflection point from the *E*- to the *F*-layer. Investigation in later years by Khastgir, *et al.* (1947) on 1000 meters, during sunset times led to similar conclusions. During the International Geophysical

Year the studies of sunrises and aunsets effect were continued with special emphasis on observations of the integrated field intensity of atmospherics (Horner 1962, 1964 ; Sen 1965). These studies revealed certain general features of the effects, observed at low and very low frequencies. However, the nature of the duration of the effects and, in particular, that of their frequency dependence is not clearly understood (Whitson 1961). Some of the interesting results obtained from an analysis of the integrated field intensity of atmospherics recorded in Calcutta (lat. 22°34N, long. 88°24E) on 30, 120 and 210 Kc/s have been presented in this paper.

Equipment

The receiving and the recording equipments used for the observations of IFIA were based upon designs adopted during the International Geophysical Year for solar flare patrolling by the s. e. a. (sudden enhancement of atmospherics) technique (Ellison 1955), with slight modifications required for handling a wide range of field intensities due to local thunderstorms. The overall time constant of the equipment is 8 seconds for a sudden increase of input level, while, it is 1 minute for a decrease.

Observations

A typical record of the integrated field intensity of atomspherics (IFIA) observed at each of the three frequencies, 30, 120 and 210 Kc/s, is reproduced in figure 1, which shows the usual diurnal variations. These are : sunrise effect (A), morning minimum (D), afternoon maximum (E), late minimum (F), and night maximum (G) (WMO 1957). The gradual fall in intensity between A and D, and a gradual rise between F and G indicate sunrise and sunset effects, respectively, in the propagation path. The sunset rise, on the majority of days is, however, obscured by meteorological activity in and around Calcutta. The sunrise fall, on the other hand, was discernible on about 80% of the days in a year thus offering a reasonable volume of date for a statistical analysis.

Statistical Characteristics of Duration

The duration of the sunrise effect at 30 Kc/s, 120 Kc/s and 210 Kc/s for each day was found out. Monthly average values as also the yearly average values of the duration were calculated. It was observed that both the monthly and the yearly average values of the duration of the sunrise effect were frequency dependent. In general, the duration decreases with increasing frequency. Moreover, the duration is a minimum, in January and in June. A similar trend as described above is, in fact, also exhibited by a typical record as shown in figure 1. To examine the nature of the frequency dependence in greater detail the logarithm of the monthly average duration, normalized at 30 Kc/s with respect to the yearly average duration at that frequency, is plotted against the frequency on a scale as shown in figure 2, which indicates that the rate of decrease of duration with frequency for a particular month is higher between 120 and 210 Kc/s than between 30 and 120 Kc/s. The seasonal variation of the rates as indicated

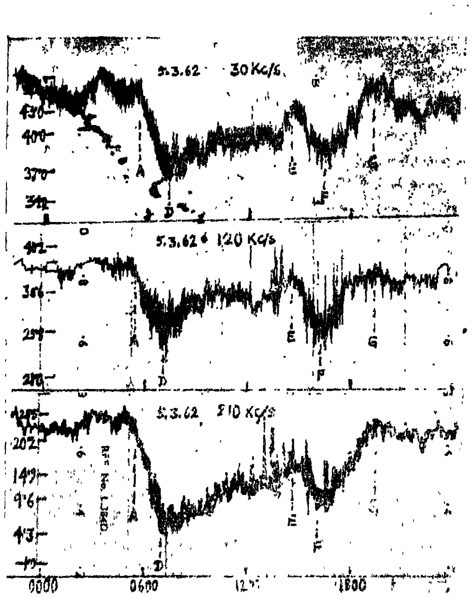

Figure 1. Photograph of a typical record of the integrated field intensity of atmospherics showing the usual diurnal variations observed on 30, 120 and 210 Kc/s at Calcutta (A : sunrise effect ; D : morning minimum ; E : afternoon maximum ; F : late minimum ; and G : night maximum). The ordinate shows the r. m. s. field strength for a 1 Kc/s bandwidth in decibels above 1 μV/m.

by the slope of a line drawn in figure 2 is shown in figure 3, in which the slope is expressed in terms of a ratio of durations at frequencies differing by one octave. The figure exhibits a remarkable seasonal dependence of the slope particularly between 120-210Kc/s for which the slope is a maximum in January and a minimum in June. The yearly average of the slopes are 1.028 and 1.065 per octave for the ranges 30-120 and 120-210 Kc/s, respectively.

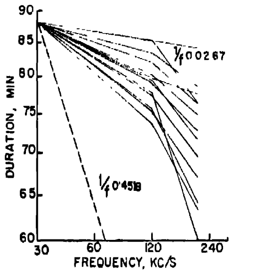

Figure 2. Frequency dependence of duration of the sunrise fall.

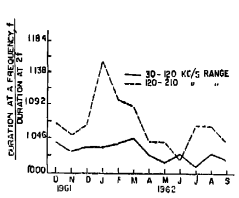

Figure 3. Seasonal variation of the ratio of durations at frequencies differing by one octave.

Upper and Lower Limits of Duration :

Table 1 shows the distribution of durations, observed at each of the frequencies over the one year period, beyond certain upper and lower limits.

TABLE 1. DISTRIBUTION OF DURATIONS BEYOND CERTAIN LIMITS.

Frequency Kc/s.	Percentage of days with durations				
	Less than 30 min	Less than 60 min	Greater than 120 min	Greater than 150 min	Greater than 180 min
30	0	7.6	13.8	2.9	0
120	0	19.3	8 4	0 7	0
210	1.3	30.1	5.7	0 3	0

The table indicates that the durations of the sunrise effect are mostly in the range 60-120 minutes. Moreover, both the lower and upper limits of the duration show marked frequency dependence.

Statistical Characteristics of the Time of Start and That of End of the Sunrise Fall :

In order to study the origin of the sunrise fall, two scatter diagrams showing the times of start and that of the end of the sunrise fall, observed at 30 Kc/s, in relation to the time of ground sunrise at the station, were drawn as shown in figure 4. It is found that the start and the end in a great majority of cases occur before and after, respectively, of the time of local ground sunrise. The diagrams also exhibit a tendency for the times of start to cluster about a line parallel to the line of local ground sunrise. A similar trend is also exhibited by the times of end. Histograms of the time advance of the start before the time of ground sunrise and that of the time delay of the end after ground sunrise for each of the three frequencies are shown in figure 5. The histograms also indicate the yearly average values of the time differences. The average of the time advance of start are 29.30, 30.06 and 31.01 minutes at 30,120 and 210 Kc/s, respectively, while that of the respective time delay of end are 60.37, 50.46 and 40.37 minutes. From these figures, it appears that the time advance of start is very slightly dependent on frequency, tending to increase with frequency, while the time delay of end is, on the other hand, fairly frequency dependent, showing a decrease with increasing frequencies. The same general nature of the frequency dependence is, in fact, exhibited by a typical record as shown in figure 1, reproduced in the preceding section.

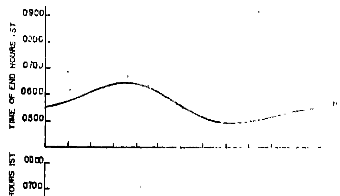

Figure 4. Scatter diagram of the time of start and the time of end of sunrise fall on 30 Kc/s against the day.

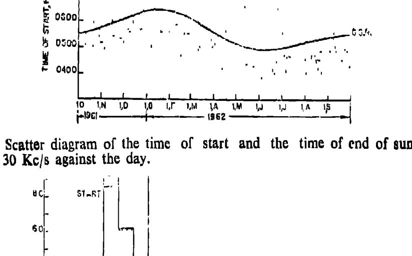

Figure 5. Histogram of the time difference between ground sun rise and start or end of sunrise fall.

Upper and Lower Limits of the Time Differences :

Table 2 shows the distribution of the time advance of start as well that of the time delay of end beyond certain upper and lower limits.

TABLE 2. DISTRIBUTION OF TIME DIFFERENCES BETWEEN GSR AND THE START OR END OF SUNRISE FALL, BEYOND CERTAIN LIMITS

Frequency Kc/s.	Percentage of days with time advance of start			Percentage of days with time delay of end	
	Less than 0 min.	Less than 15 min	Greater than 75 min.	Less than 0 min.	Greater than 90 min.
30	7.9	5.9	4.3	0.4	11.2
120	8.2	6 0	6.0	0.4	10.1
210	8 5	5.9	6.3	3.7	7.7

The table indicates that the time advance of start beyond the range—15 to 75 min is of the order of 6%, while those less than 0 minute is about 8%. The delay of end less than 0 minute is under 4% while that greater than 90 minute is about 10%.

DISCUSSION

Various authors observed the sunrise and sunset effects and tried to explain the phenomena in terms of source distribution and changes in the state of ionisation in the propagation path due to the impact of solar ionising radiations. Lugeon (1929) first reported that the start of sunrise effect always occurs before the local ground sunrise. Lauter (1958) observed from measurements of 27 Kc/s and 40 Kc/s atmospherics that the main drop in intensity occurred when the sun's zenith angle was about 99°40′. Reiker (1960) explained the latest time of start in his observations of the sunrise effect at 27 Kc/s as due to the most distant western sources. Chiplonkar & Karekar (1963) tried to explain the times of start and end of the sunrise fall observed at 27Kc/s in Poona, in terms of a single hop reception from eastern and westerm sources lying within the geometrical optical horizon. It was, however, felt that some of their assumptions required a modification in the light of the present knowledge of radio wave propagation at low frequencies (Aikin 1962 ; Belrose 1964a, 1964b ; Davies 1965 ; Deeks 1965). Such a modified approach will be tried in order to explain our observations at 30, 120 and 210 Kc/s.

The geometry of the problem is illustrated in figure 6, which shows an east-west section through the station and the centre of the earth.

For any position of the receiver, R, there exist two farthest sources, S_1 and S_2, from each of which radio waves can be received by a single hop

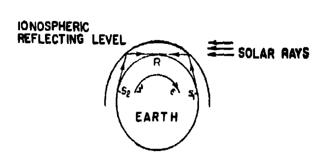

Figure 6. An east-west section through the station and centre of the earth

transmission. For such sources, the path of propagation will be tangential to the earth's surface at R.

Recent measurements of the phase of the sky wave at low frequencies at a range of 1900-2400 km indicated that the "phase height" of reflection begins to decrease about an hour before ground sunrise at the path mid-point, corresponding to a solar zenith angle of 101°, when visible light from the sun impinge on the ionosphere at a height of 85 km after grazing the ground (Belrose 1964a). In our case as the propagation paths are tangential to the earth's surface, the times of impingment of solar rays at the path midpoints for the sources at S_1 and S_2 will be the same as the times of ground sunrise at S_1 and R, respectively, and if we assume the absorption of the wave to start when the solar rays strike the night-time reflecting layer at the path midpoints, the earliest and latest start of the sunrise fall would occur at these times of ground sunrise at S_1 and R, respectively. If the earth's radius be taken as 6378 km then for a height of reflection equal to 85 km the earliest start would occur about 75 minutes before ground sun-rise at R. Our observations at each of the three frequencies indicate that there are only about 6% of cases, in which the start is earlier than 75 minutes before ground sunrise at R. The results are thus in fairly good agreement with those expected for a one-hop model discussed above. The observed lack of frequency dependence for the number of cases occuring beyond 75 minutes suggests that the time of the earliest start is not frequency dependent in the range 30-210Kc/s. This implies that the height of reflection at night for such an oblique path does not vary over the frequency range involved. So far as the time of the latest start is concerned, our observations at each of the frequencies indicate that there are only 8% of the cases in which the start occurs after ground sunrise at R, when the latest start is expected. Of these cases in which the occurrence of the latest start is delayed, about 6% occur with delays greater than 15 minutes. The time of the earlies tand the latest ends of the sunrise fall would be the same as the time of the end of sunrise fall for the paths RS_1 and RS_2, respectively. Our observations at each of the three frequencies show that in less than 4% of the cases ends occur immediately after ground sunrise at R, while in about 10% of the cases the ends occur 90 minutes after ground sunrise at R.

It is interesting to note that of csaes with their ends occurring 90 after ground sunrise at R do not exhibt any signiflcant frequenmincy dependence. This suggests that the absorbing regions of the lower ionosphere behave in the same way to radio waves of frequencies in the range 30-210 Kc/s, when propagation to distances of the order of 2000 km are considered

In the foregoing discussions, we have assumed the sources to be distributed along a east-west line through the station. However, the sources are, in general, widely scattered in various directions and one should take into account the role of a source in any direction on the observed time of start and end of the sunrise fall. As an approximation, if the height of the night-time reflecting layer be assumed to be constant all around the station, the farthest sources will lie on a circle of radius about 2000 km with the station at the centre (Sen 1968). The corresponding path midpoints will lie on a second circle of half the radius, 2000 km, for the farthest sources. Interruption of reception would occur earliest for an eastern source, which is situated at the point of contact of the line of sunrise with the second circle. The point of contact is farthest in the east in some parts of the year when the line of sunrise is oriented north-south at the point of contact. The start is, therefore, the earliest for the farthest eastern sources, at such times. A similar reasoning will show that the start would be the latest for the farthest western sources. In case, the sources are absent in the farthest eastern and western positions, the earliest start of the sunrise fall will obviously occur later, while the latest start will occur earlier than those expected from the above explanation. In fact, if the sources are distributed purely in the north-south directions the times of the earliest and latest start would be the same and equal to the time of sunrise at the reflection point just above the station.

The time-advance of start as well as that of the time-delay of end were also examined in greater details. A plot of the monthly average values of the time differences against the corresponding month is shown in figure 7. From the figure it is evident that the frequency dependence of the duration of sunrise fall arises mainly from the dependence of the time of end on frequency, the contribution arising from any dependence of the time of start being negligible. In contrast to this, both the times of the earliest and latest end of the sunrise fall exhibit no marked frequency dependence (table 2). The above results could, however, be reconciled if one assumes a frequency-distance dependence of reflection coefficient of the ionospheric region involved, of the type observed by Belrose (1964b).

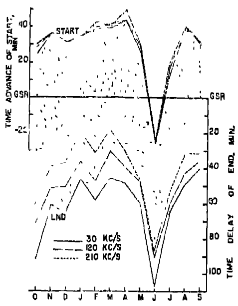

Figure 7. Seasonal variation of the monthly average time difference between ground sunrise G. S. R. and start or end of sunrise fall.

His results indicated that the absorption of a wave of frequency f, incident at an angle i, to the reflecting layer would be the same as that of a wave of 'effective frequency' f_e, incident vertically such that $f_e = f\cos i$ (Allock 1955 ; Belrose 1964). Considering, first, the case for the earliest and latest end, it could be observed that the sources corresponding to these cases are on the geometrical optical horizon for a one hop ray, i. e., about 2000 km from the observing centre. The angle of incidence for this range is 80°40′, which gives an effective frequency of about 5, 20 and 35 Kc/s corresponding to the observing frequencies 30, 120 and 210 Kc/s, respectively. The reflection coefficient in this range of 5-35 Kc/s, however, does not exhibit any marked frequency dependence and as such it is not surprising that a similar lack of frequency dependence is observed for the times of the earliest and latest ends. As regards the observed dependence of the monthly average time of end on frequency, our analysis indicates that the sources contributing towards this average result, are located somewhere between the observing station and the geometrical optical horizon for a one hop ray. If the great majority of the sources be located midway between the two extremes, as is also apparent from the monthly average time of end, their distances from the observing centre would certainly be less than 2000 km, which implies that the effective frequencies would be more widely spaced in the $f\cos i$-axis, thus leading to a significant frequency dependence of reflection coefficient. This appears to explain why the frequency dependency, although insignificant for the earliest and latest ends could be appreciale for the monthly average time of end.

It may be noted that the role of any multihop ray within the geometrical optical horizon has not been considered in the present analysis. However, such rays are, in fact, always present as is evident from a study of the waveform of propagated atmospherics where they appear in the form of a succession of weaker pulses following a primary atmospheric pulse due to the one-hop ray. Nevertheless, such secondary puleses are of rapidly diminishing magnitudes and their contribution in the integrated field intensity of atmospherics, if any, are only of secondary importance.

In the above discussion it has been assumed that the solar rays grazing the ground is responsible for the earliest and latest start of a sunrise fall. Such ground-grazing rays are, however, devoid of the usual ionizing radiations as they would be absorbed in passing through the atmosphere producing the ozonosphere (Mitra 1938). Naturally some alternative mechanism of ionization must be sought, in which only the visible radiation of wavelengths longer than the upper limit of the Hartley band of ozone is involved. Such a mechanisn has, in fact, been suggested to explain the formation of a so called "Cosmic-ray layer" developing below the *E*-region immediately after sunrise (Reid 1961; Whitten & Poppoff 1965). At low frequencies reflection from this layer occurs when propagation to distances of the order of 2000 km or greater are involved (Belrose 1964). Ionization in the layer has a basic component produced by cosmic rays incident equally by day and night. But when the sun's light impinges on the layer, a predominance of photodetachment of negative ions relative to that of attachment causes the free electrons to be more numerous (Aikin 1962). Consequently, the sunrise effect is expected to occur immediately after the impingment of a ground grazing visible light from the sun at the appropriate height. In support of the above discussion, reference may be made to a recent review of *D*-region processess in non-polar latitudes by Mitra (1968), who indicated the importance of high affinity negative ions in explaining the sunrise-sunset effects in the LF and VLF bands and the "twilight" anomaly of polar-cap absorption events (Reid 1961). It may be mentioned here that for propagation to distances less than about 1500 km, the cosmic-ray layer is penetrable and the sunrise fall would then occur due to the absorption by the normal *D*-region formed by the ionizing radiations grazing the ozonoshere. It is now believed that x-rays and ultraviolet rays from the sun are the important ionizing agents for the normal *D*-region (Whitten & Poppoff 1965).

Conclusion

Summarising what we have said, it may be concluded that the duration, times of start and end of a sunrise fall, as also their frequency dependence could be explained approximately in terms of a single hop propagation of radio waves at low frequencies, from sources lying within the geometrical optical horizon. For a more accurate interpretation additional propagation due to multihop rays, which become important particularly at great ranges, must also be taken into account. Recent measurements by Hargreaves' Roberts (1962) of the field strength of a c. w. transmission at 19.6 Kc/s have, in fact, revealed that a two hop component is not negligible, particularly in winter, for a range of the order of 1000 km. The multihop propagation becomes more and more important with increasing ranges until beyond about 1500-2000 km, the number of multihop paths becomes large.

Studies of sunrise effect by employing a radio transmission at low frequencies are handicapped by interference from atmospherics, which tend to obscure the end of sunrise fall, when the absorption is a maximum. Studies using atmospherics, on the other hand, effectively harnesses the powerful electromagnetic radiation from lightning discharges. Such studies, if supplemented by directional observation might prove to be useful in providing us with a better understanding of the phenomena occurring near sunrise. It must, however, be admitted that both the location and activity of a source of atmospherics exhibit a high variability and great care must, therefore, be taken in separating out any propagation effect from an observation of atmospherics.

The authors are grateful to Prof. J. N. Bhar, D. Sc., F. N. I., Director, Centre of Advanced Study in Radio Physics and Electronics, University of Calcutta, for his constant encouragement.

References

Aikin, A. C. 1962 *Radio Wave Absorption in the Ionosphere, AGARDograph* **53**, (*ed. N. C. Gerson*), Pergamon Press, 287.

Allock, G, Mck. 1955 *Physics of the Ionosphere, Physic Society, London*, 14.

Belrose, J. S. 1964a *Propagation of Radio Waves at Frequencies below 300 kc/s, AGARDograph* **74**, (*ed W. T. Blackband*), Pergamon Press 3.

Belrose, J. S. 1964b *Propagation of Radio Waves at Frequencies below 300 kc/s. AGARDograph* **74**, (*ed. W. T. Blackband*), Pergamon Press, 149.

Chiplonkar, M. W. & Karekar, R. N. 1963 *J. Atmosph. Terr. Phys*, **25**, 23.

Deeks. D G. 1965 *D-region Electron Distributions in Middle Latitudes deduced from the Reflection of Long Radio Waves Science Research Council, Radio and Space Research Station Slough, England, Internal Memoranda No.* 219.

Ellison, M, A. 1955 *URSI Information Bulletin No*, 92.

Hargreaves, J. K. & Roberts, R. 1962 *J. Atmosph. Terr. Phys.*, **24**, 435.

Horner, F. 1962 *Radio Noise of Terrestrial Origin*, (*ed. F. Horner*), Elsevier Publishing Co., *N. Y.* 40.

Horner, F. 1964 *Advances in Radio Research* (*ed. J. A. Saxton*), Academic Press, *N. F.* **2**, 121.

Khastgir, S. R. & Ali, M. I. 1942 *Indian J. Phys.*, **15**, 399.

Khastgir S. R.. Das Gupta, M. K. & Ganguli, D K., 1947 *Indian J. Phys*, **21**, 169.

Lauter, E. A. & Schmelovsky, K. H. 1958 *Gerlands Beitrage Geophys.*, **67**, 218.

Lugeon, J., 1929 *C. R. Acad. Sci. Paris*, **188**, 1690

Mitra, A. P., 1968 *J. Atmosph. Terr. Phys.*, **30**, 1065.

Namba, 1933 *Proc. IRE*, **21**, 238.

Potter, R. K. 1931 *Proc. IRE*, 19, 1731.

Reid. G. C., 1961 *J. Geophys Res.*, **66**, 4071.

Ricker, J. 1960 *J Geophys. Pure Appl.*, **46** 241.

Sen, A. K. 1965 *J. Sci. & Industr. Res.* **24**, 571.

Sen, A. K. 1968 *Studies on the Integrated Field Intensity of Atomospheric at Calcutta, Doctoral Thesis Calcutta University.*

Thomas, H. A. & Burgeses, R. E. 1947 *Radio Research Special, Report No.* 15, *Department of Scientific and Industrial Research, London.*

Whitten, R. C. & Poppoff, I. G. 1965 *Physics of the Lower Ionosphere, Prentice Hall, Inc.*

Whitson, A. L. 1961 *Report . SRI Project No.* 3171, *Stanford Research Institute, California.*

WMO, 1957 *Final Report of the Working Group of Atmospherics, World Meteorological Organization.*